The Future of X-ray Astronomy

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Theme

In the first 40 years of X-ray astronomy we increased sensitivity by a factor of 10^9, image resolution by 2.5×10^5, spectral resolution by 10^4, timing resolution by 10^4. How do we keep this progress up for the next 40 years ?

- High sensitivity, high resolution spectroscopy.
- Polarimetry
- Interferometry

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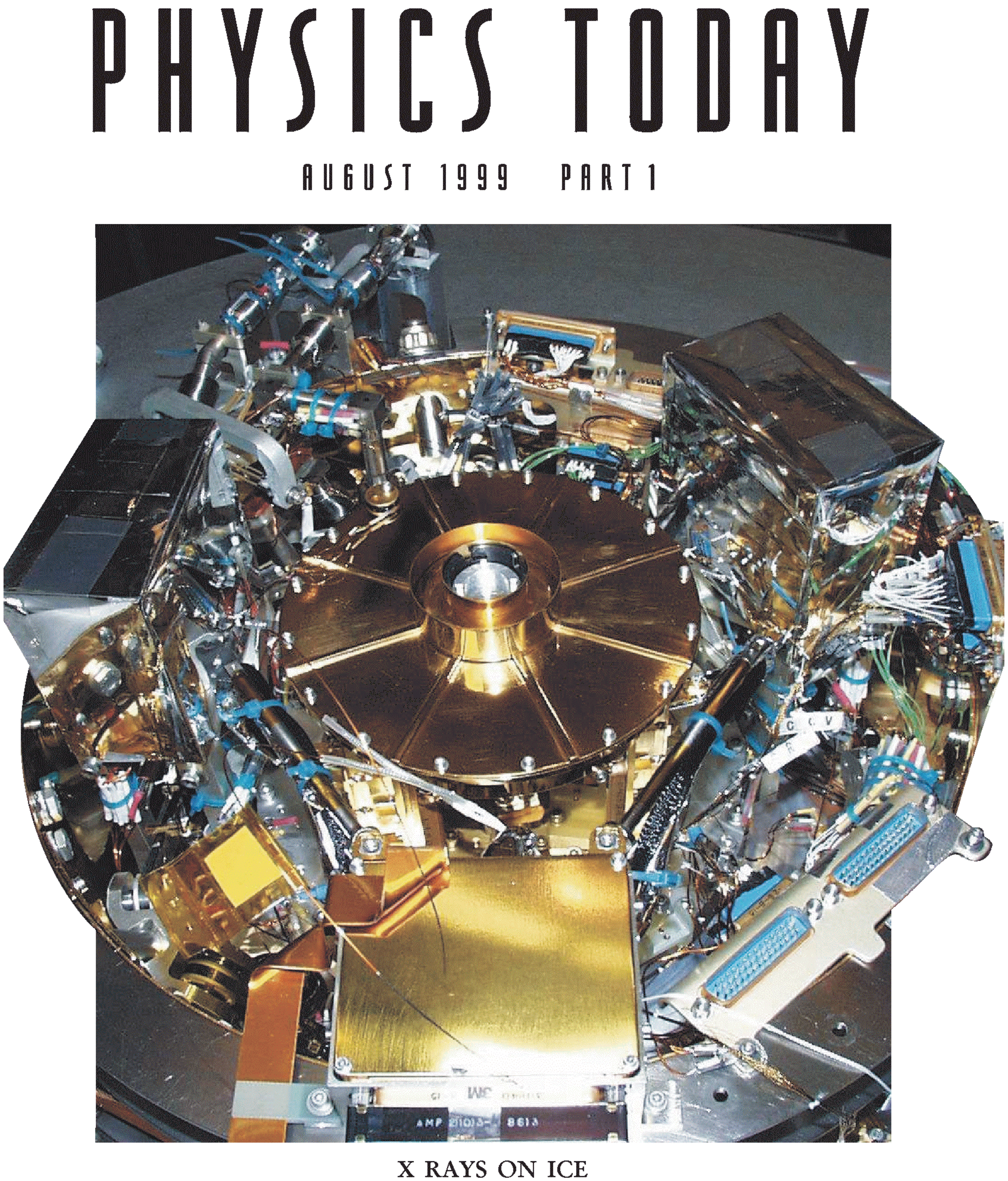


X-rays on Ice

The XRS X-ray microcalorimeter built for Astro-E (the fifth Japanese X-ray astronomy satellite)

Resolution :
9 - 12 eV FWHM
(0.5 - 10 keV)

Inserting the He dewar in the Ne dewar

A solid Ne dewar outside a liquid He dewar outside an adiabatic demagnetization refrigerator.

Astro-E Launch - February 2000

20 seconds
and going
well

Uh - oh

You really don't want to see this

Astro-E is being rebuilt as Astro-E2 and will be launched in Feb 2005.

Rebuilt calorimeter now has resolution of 6 eV.

03

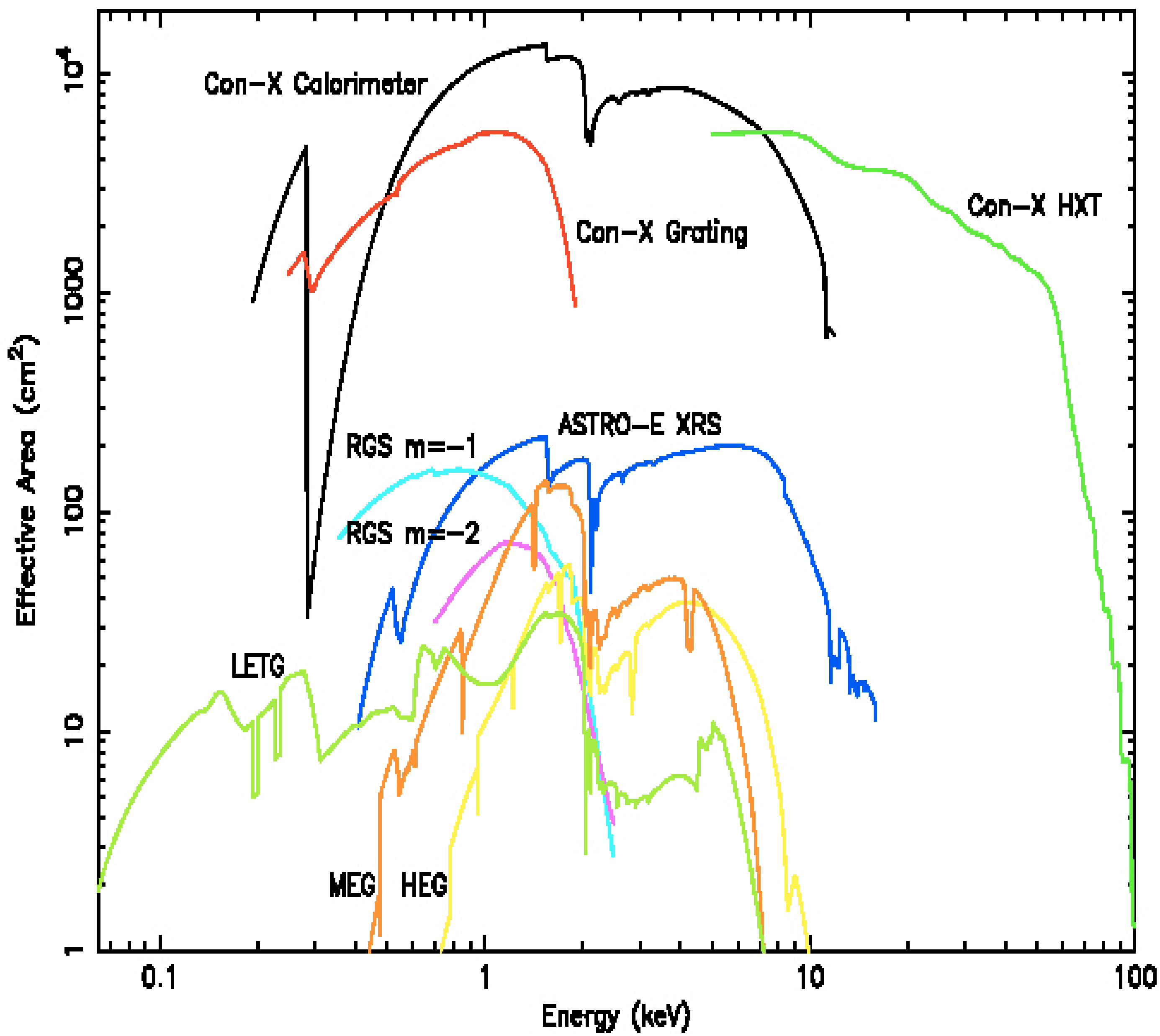

Constellation-X

Constellation-X Overview

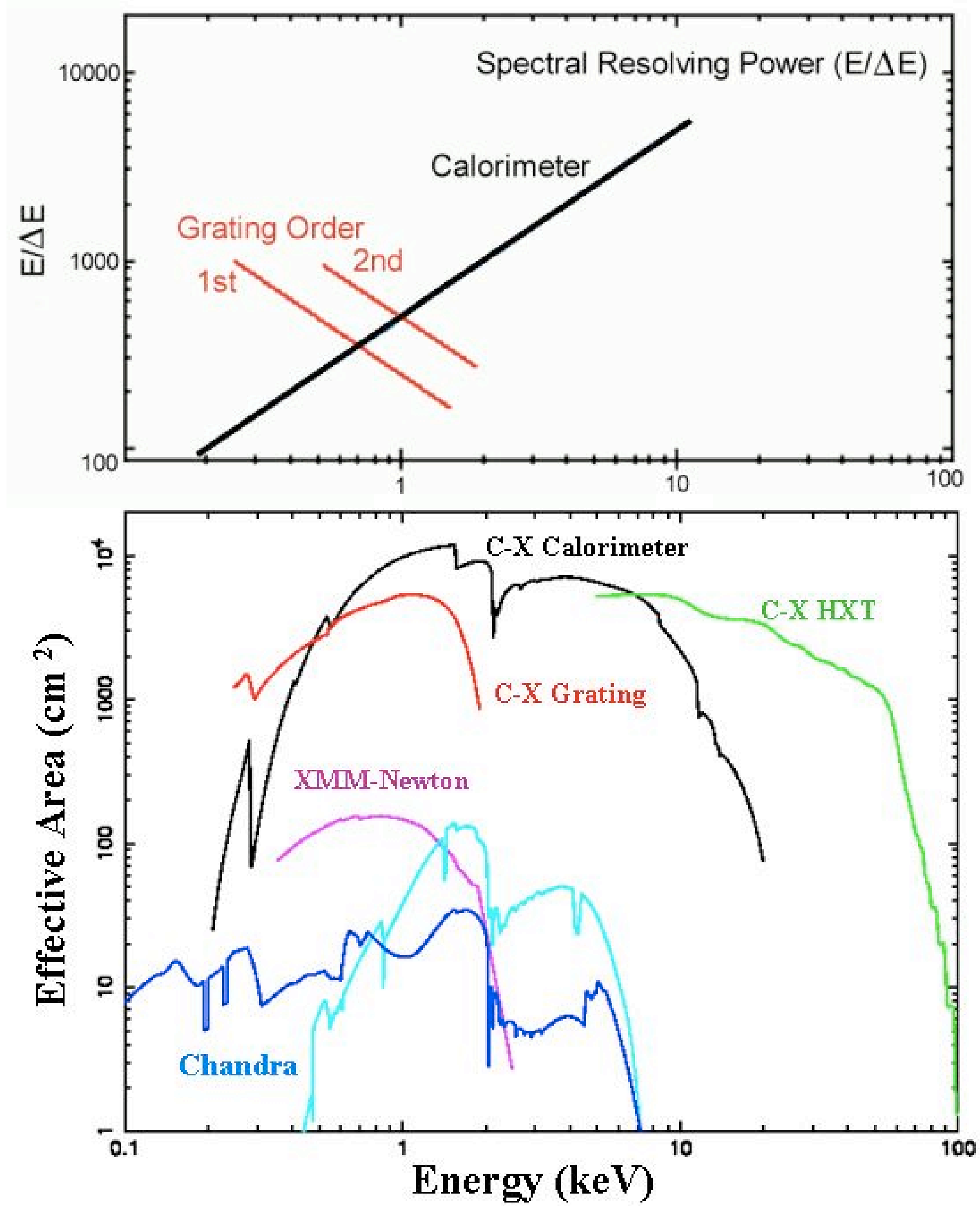
- **Use X-ray spectroscopy to observe**
  - Black holes: strong gravity & evolution
  - Large scale structure in the Universe & trace the underlying dark matter
  - Production and recycling of the elements

- **Mission parameters**
  - **Telescope area:** 3 m^2 at 1 keV
    100 times XMM/Chandra for high res. spectra
  - **Spectral resolving power:** 300-3,000
    5 times improvement at 6 keV
  - **Band pass:** 0.25 to 40 keV
    100 times more sensitive at 40 keV

X-ray School 2003

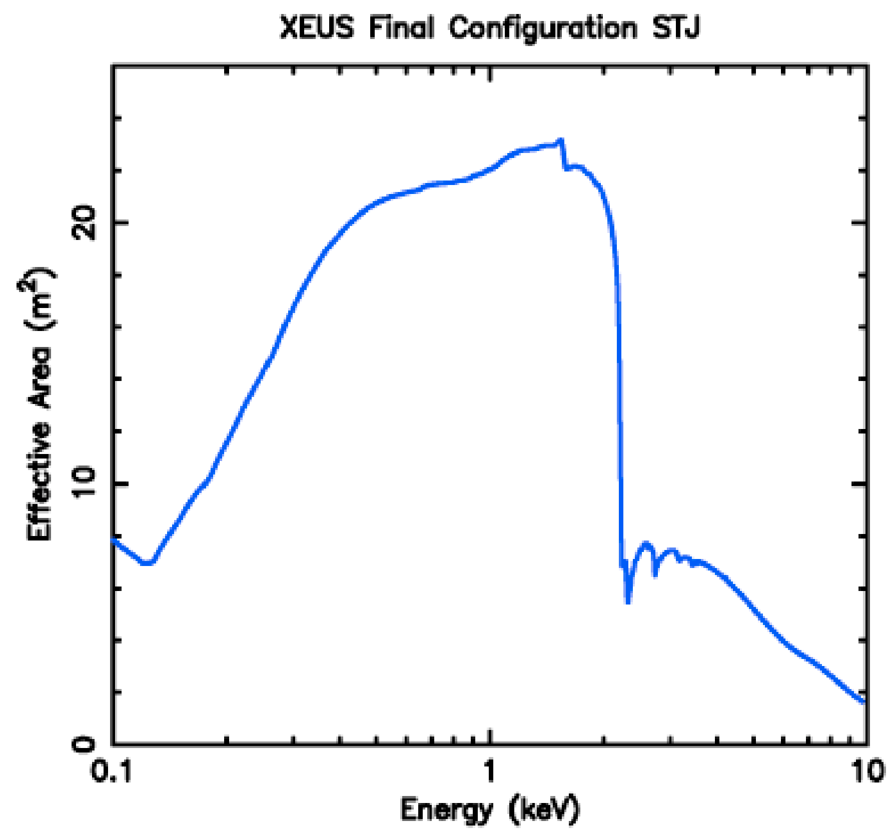


Con−X Calorimeter
Con−X Grating
Con−X HXT
ASTRO−E XRS
RGS m=−1
RGS m=−2
LETG
MEG
HEG
Effective Area (cm^2)
10^4
1000
100
10
1
0.1
1
10
100
Energy (keV)


Spectral Resolving Power (E/ΔE)
E/ΔE
10000
1000
100
1
10
100
Calorimeter
Grating Order
1st
2nd
C-X Calorimeter
C-X Grating
C-X HXT
XMM-Newton
Chandra
Effective Area (cm 2)
10⁴
1000
100
10
1
0.1
Energy (keV)

XEUS

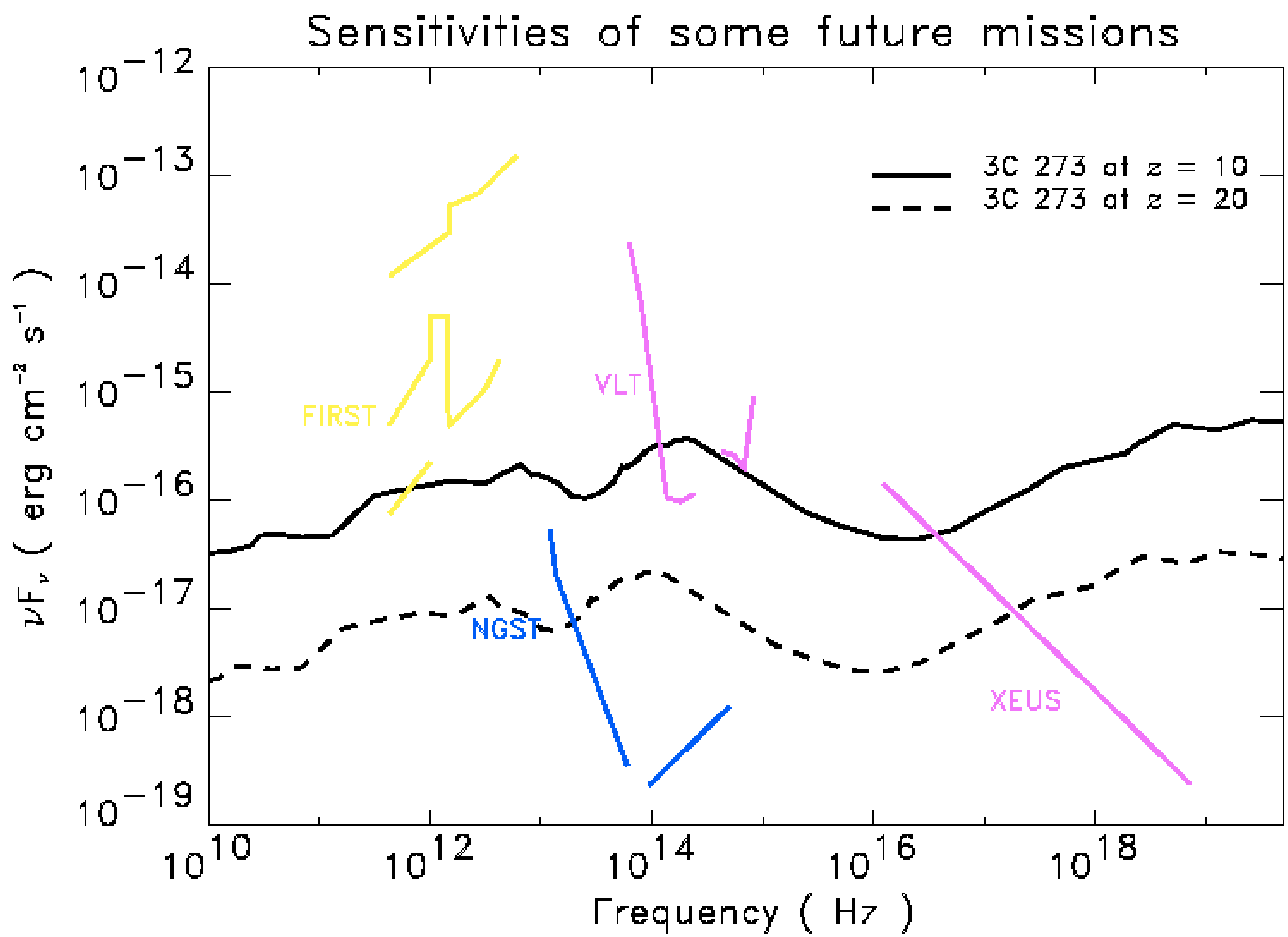
- ESA proposed mission for low Earth orbit.
- 6 m^2 of collecting area at 1 keV.
- Imaging resolution goal of 2" HEW (Half Energy Width) at 1 keV.
- Limiting sensitivity 100 times deeper than XMM-NEWTON.



- Spectral resolution of 1 to 10 eV between 0.05 and 30 keV.

XEUS II

- After completion of the initial 4-6 year mission phase, XEUS will rendezvous with the ISS for refurbishment and adding extra mirror area.
- New detector spacecraft with next generation of focal plane technologies.
- Grown mirror will have 30 m^2 collecting area at 1 keV; 3 m^2 at 8 keV.
- Sensitivity 250 times better than XMM-NEWTON.



Sensitivities of some future missions
3C 273 at z = 10
3C 273 at z = 20
FIRST
VLT
NGST
XEUS
νF_ν (erg cm^{-2} s^{-1})
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{10}
10^{12}
10^{14}
10^{16}
10^{18}
Frequency (Hz)

Generation X

- Scientific goal: to probe the X-ray emission from the universe at $z = 5\text{-}10$.
- An effective area of 150 m^2 at 1 keV with an angular resolution of ~ 0.1 arc second.
- Detect sources 1000 times fainter than Chandra (flux limit of 2×10^{-20} ergs/cm^2/s).
- Obtain high resolution spectra from sources 100-1000 x fainter than observable by Constellation-X.
- Six identical satellites with 40 to 150 m focal length to L2.

Telescope Evolution

	No. of mods	**Angular HPD**	**Eff. Area @ 1 keV (cm^2) per mod.**	**Mass (kg) per mod.**	**Notes**
Chandra	1	0.5"	1,000	1,000	Ground and polished glass shells
XMM-Newton	3	15"	1,500	420	Replicated Ni shells
Astro-E	5	90"	400	12	Replicated Al segments
Constellation-X	4	15"	7,500	420	Material and technology under study/development
Generation-X	6	0.1"	250,000	3,000	Materials and fabrication technology to be determined

- High sensitivity, high resolution spectroscopy.
- Polarimetry
- Interferometry

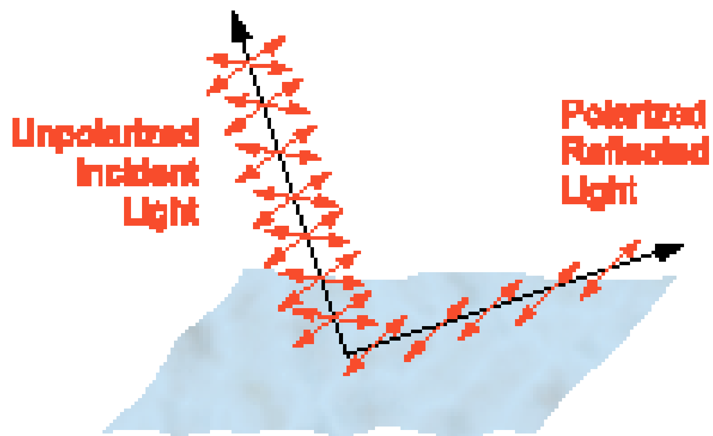
Why X-ray Polarimetry ?

- Because it's there ! Whenever we look at the Universe in a new way we make unexpected discoveries.

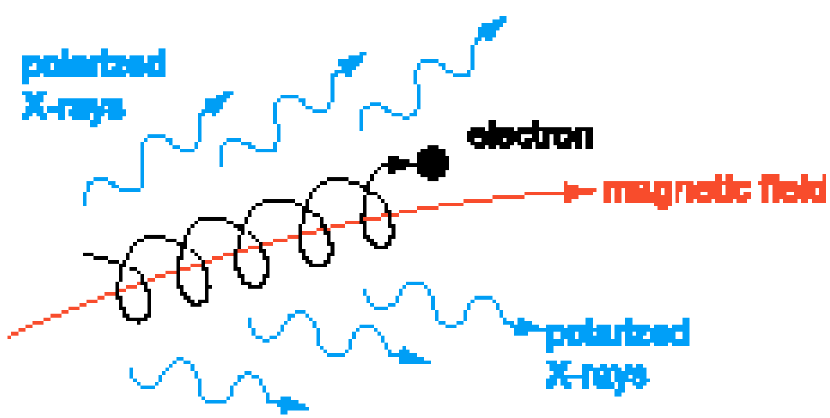
- We expect polarization from X-ray synchrotron sources such as SNR and jets. Also from X-ray reflection in binaries and AGN.

Polarization mechanisms

POLARIZATION REVEALS THE GEOMETRY OF MATTER AND MAGNETIC FIELDS



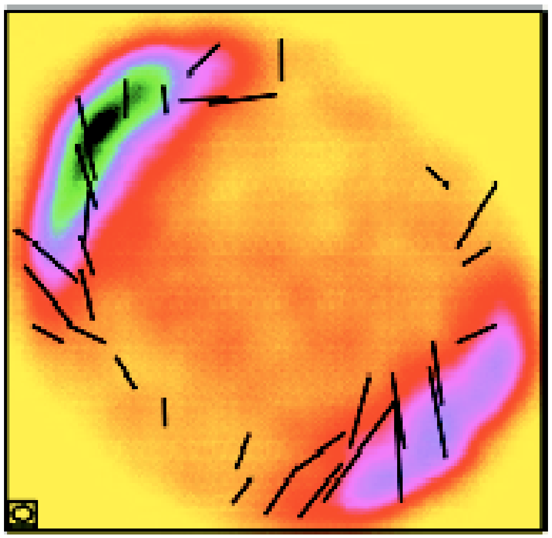
Scattering induces polarization.



Synchrotron emission in a strong magnetic field.

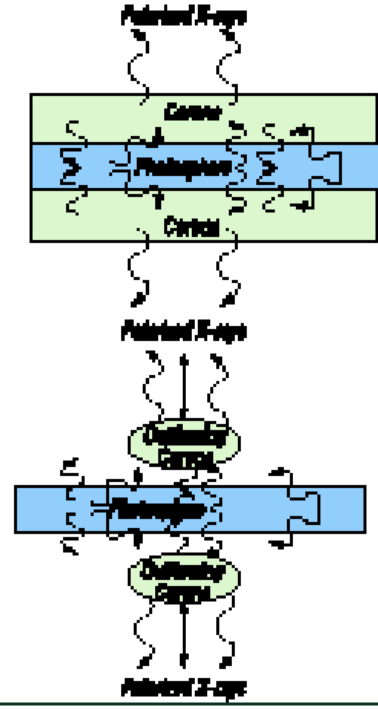
Examples

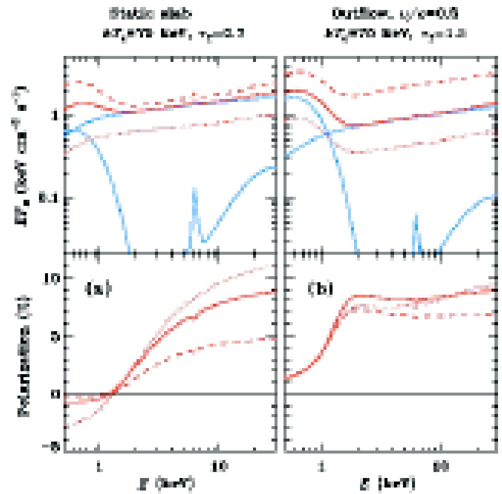
C — DISSECTING SUPERNOVA, THE SITES OF COSMIC RAY ACCELERATION



The ASCA X-ray Image of SN1006 showing the position angles and strengths of X-ray polarization vectors (white bars) assuming that it is the same as the polarization measured in the radio. AXP detection and mapping of X-ray polarization will prove the electrons are accelerated to ~ 100 TeV in supernova remnants and also determine the magnetic field geometry in several remnants.

F — PROBING THE ENVIRONS OF BLACK HOLES

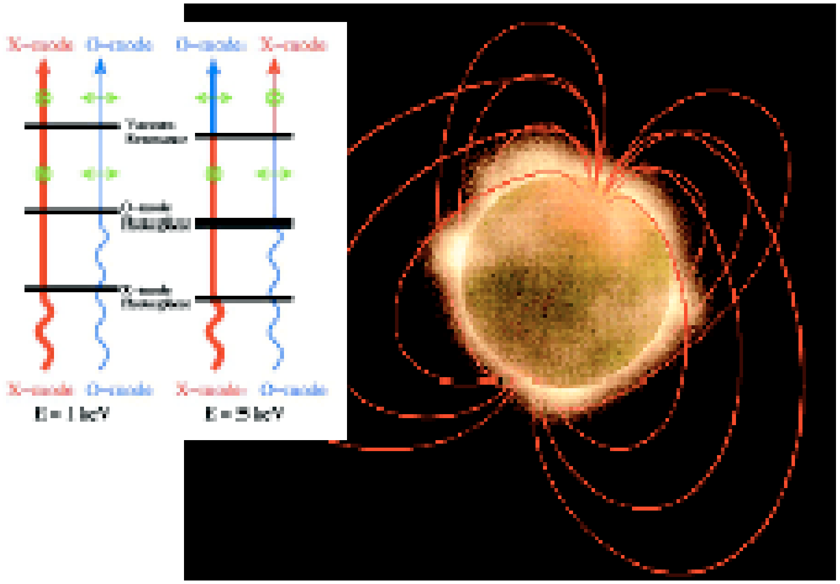


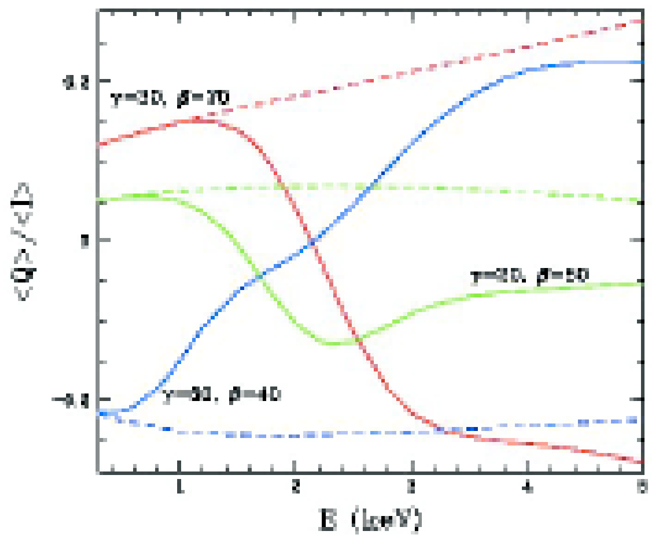


Calculated spectra (top) and polarization for two different black hole accretion geometries: a planar corona above the disk (top left), and a jet-like corona (lower left). Polarization can distinguish the two models.

Testing QED

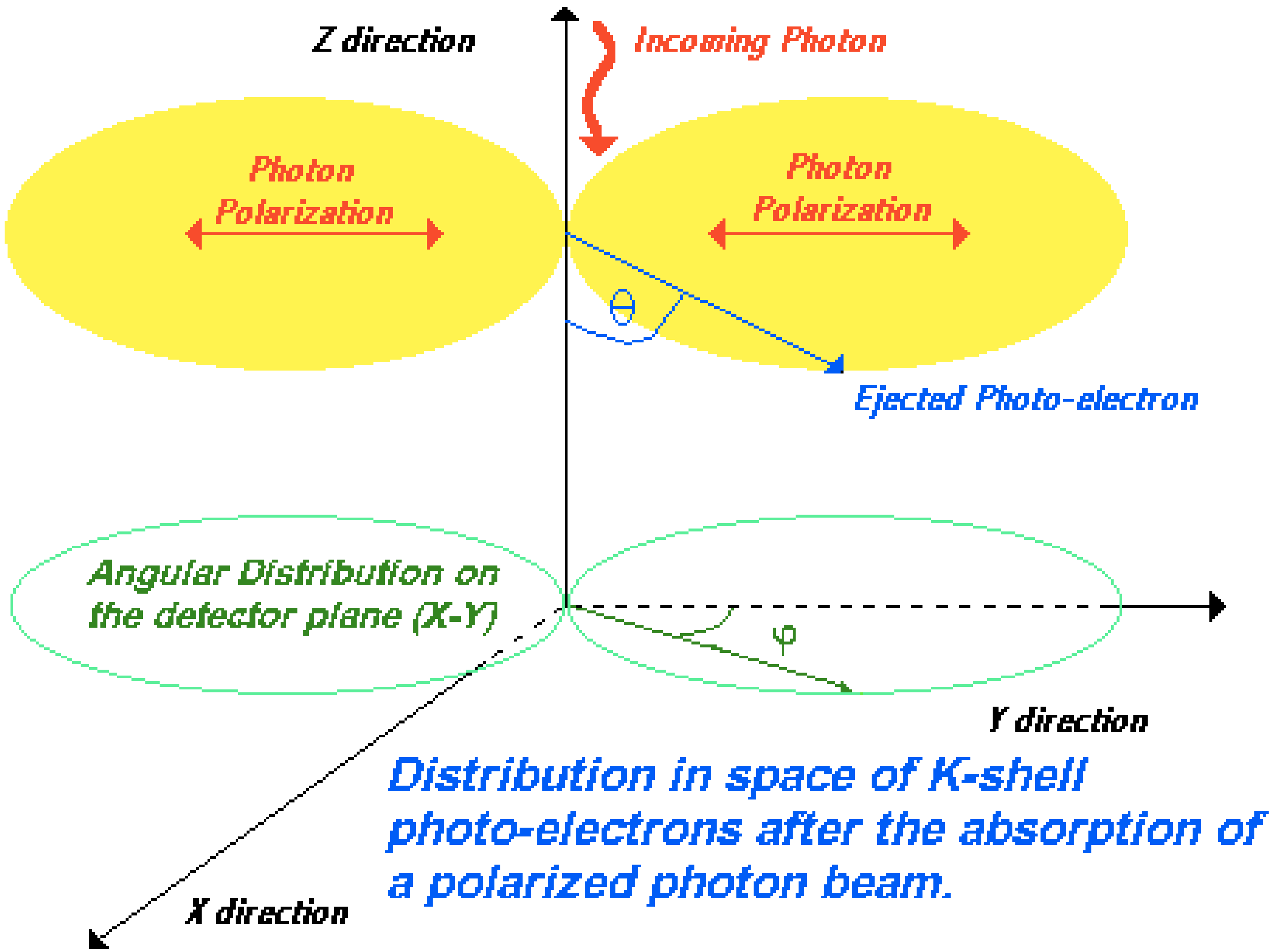
Do the predictions of quantum electrodynamics (QED) hold in the strong magnetic fields of neutron stars?





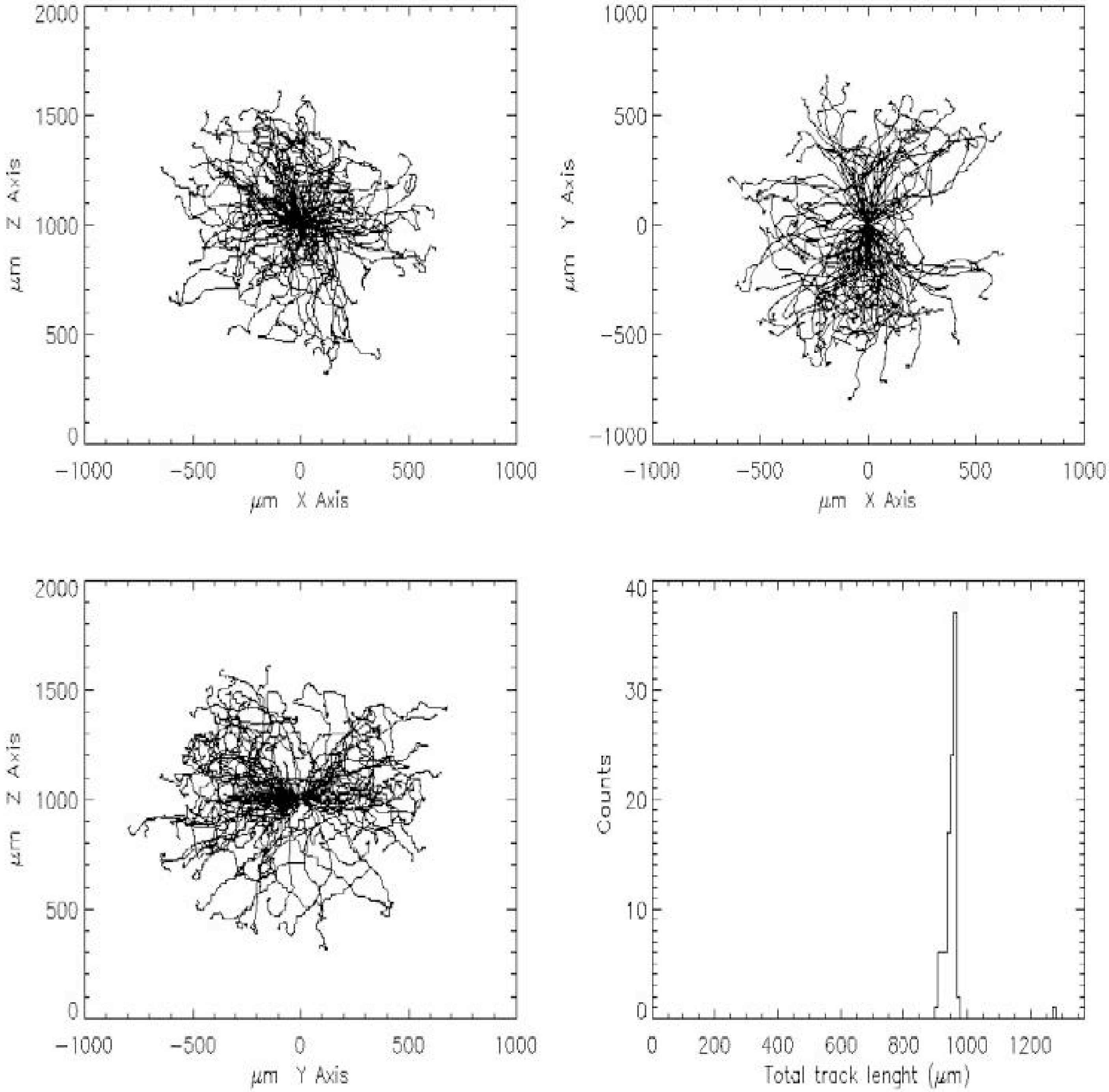
But can we detect X-ray polarization ?

- There is one detection of X-ray polarization - that of the Crab Nebula SNR.
- No X-ray polarimeter has flown on a satellite since the 1970s.
- There is a new idea for a more efficient polarimeter…



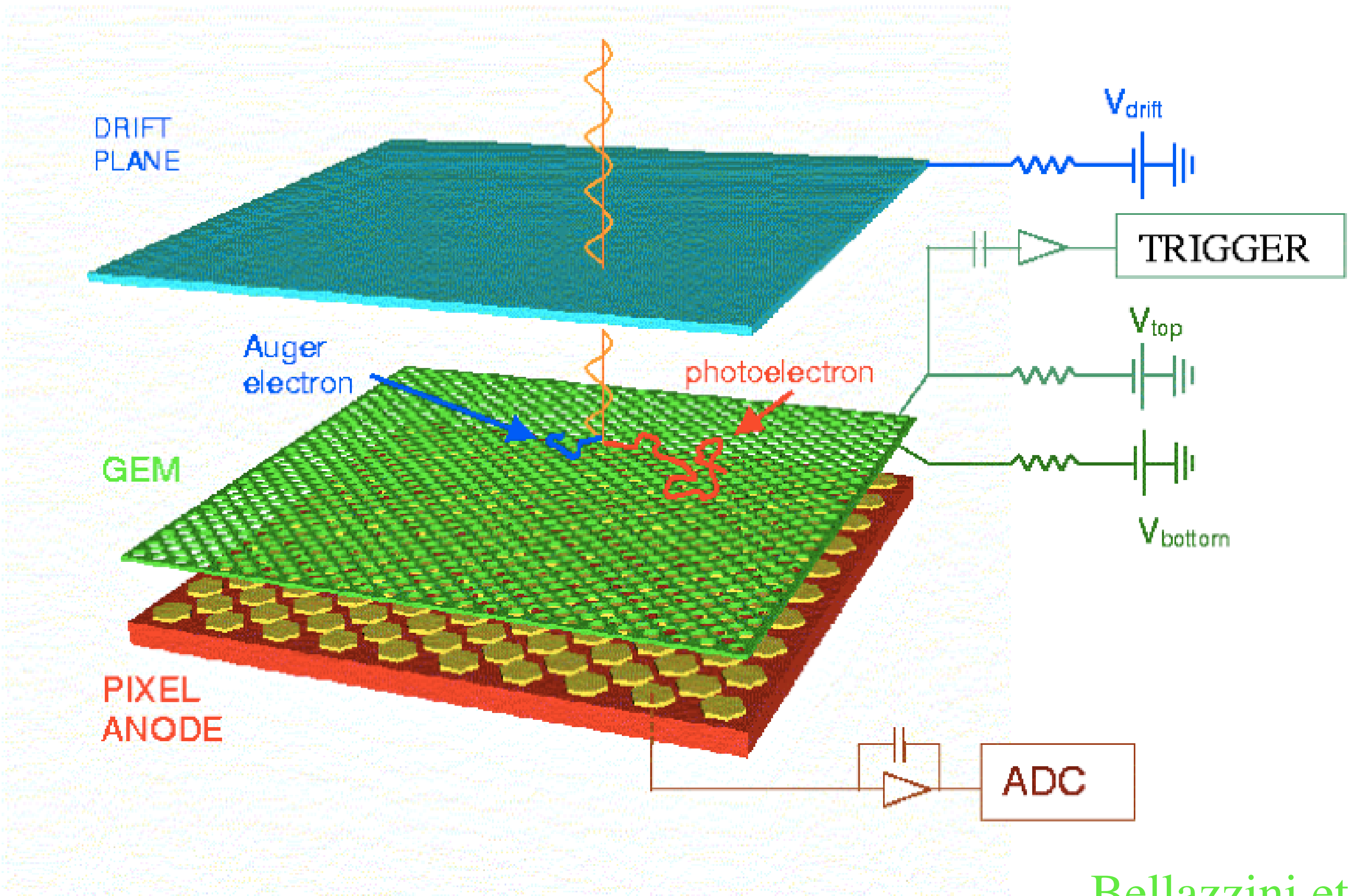
Measuring Polarization

Electron Tracks



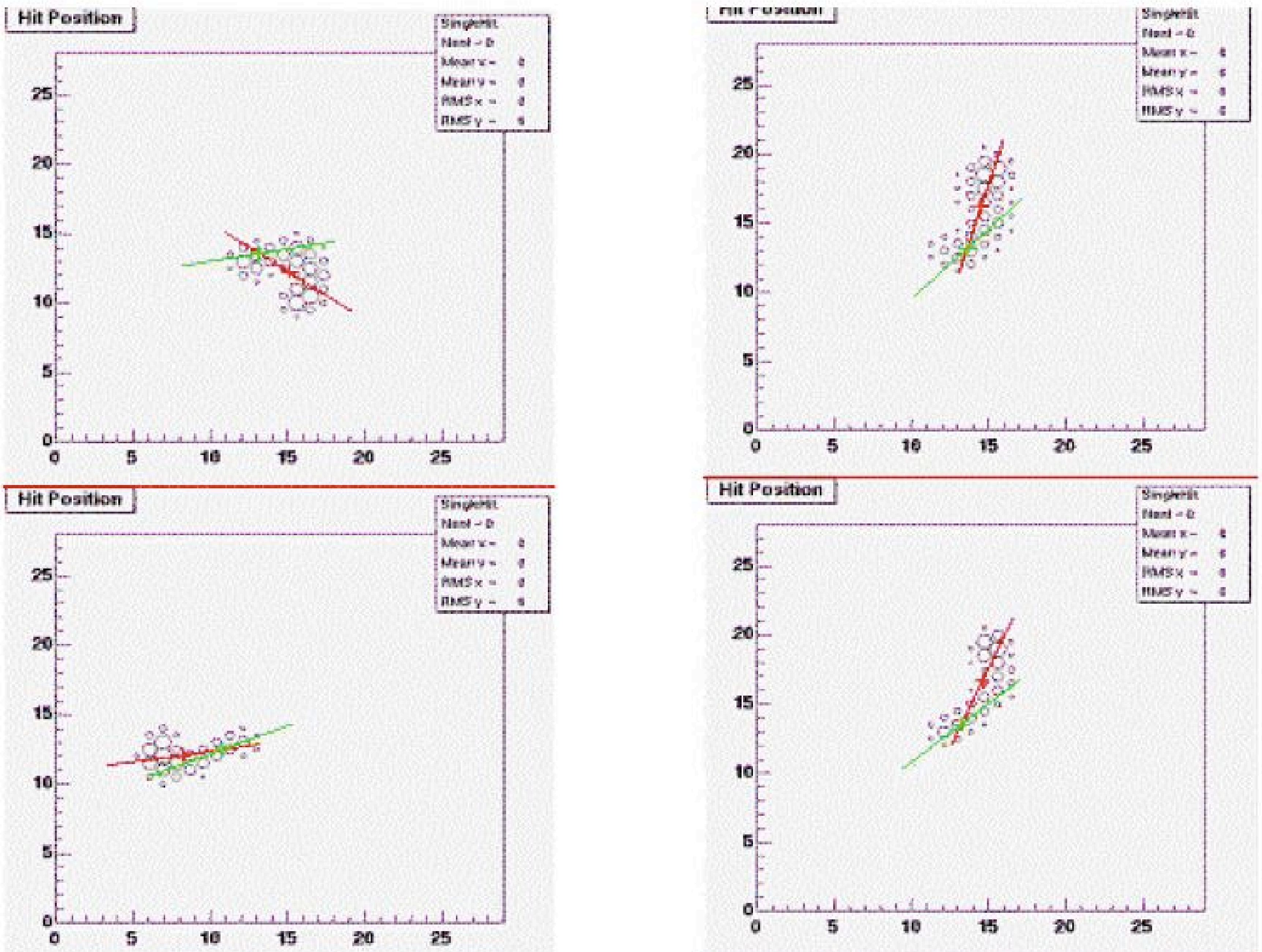
Bellazzini et al.

Microwell detector



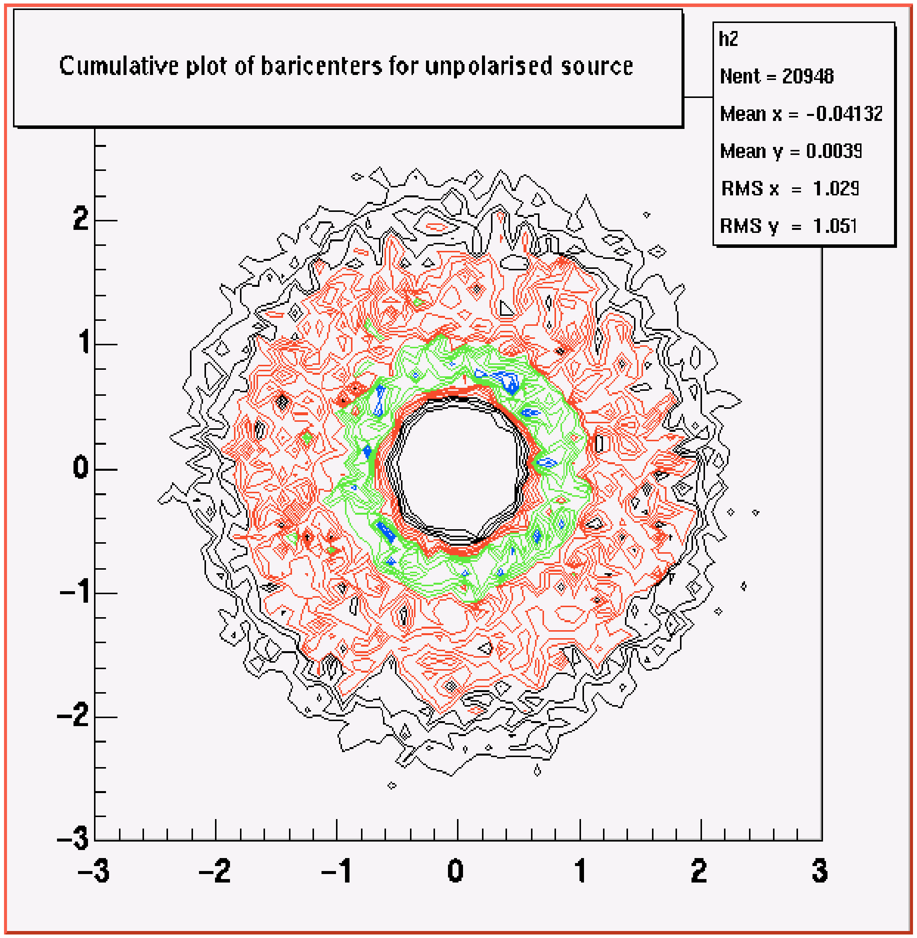
Bellazzini et al.

Bellazzini et al.

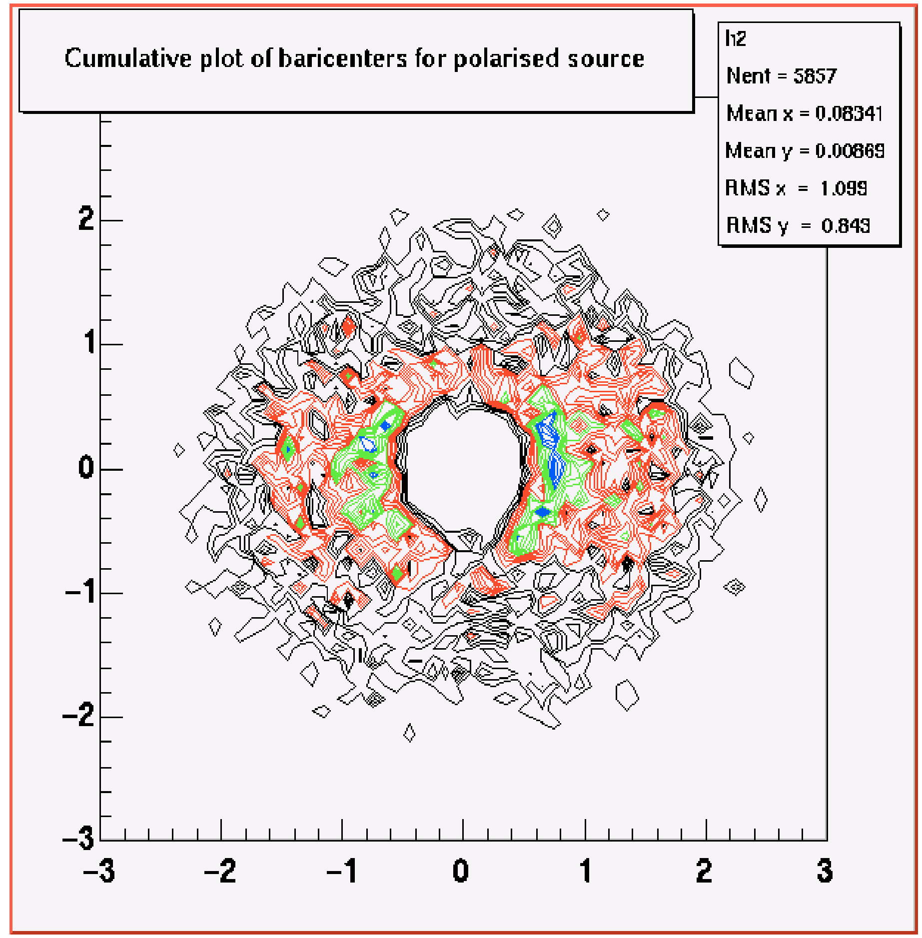


Accumulation of many events

5.9 KeV unpolarized



5.4 KeV polarized



Bellazzini et al.

- High sensitivity, high resolution spectroscopy.
- Polarimetry
- Interferometry

X-ray Interferometry

- While astronomical sensitivity has increased by a vast factor imaging resolution has not. HST is only 100 times better than Galileo's telescope.

- To do better requires interferometry.

- Radio interferometry is well developed but baselines are very long and few sources have high enough surface brightness in the radio band.

- Optical interferometry is in the experimental stage and milliarcsec resolutions should be achievable.

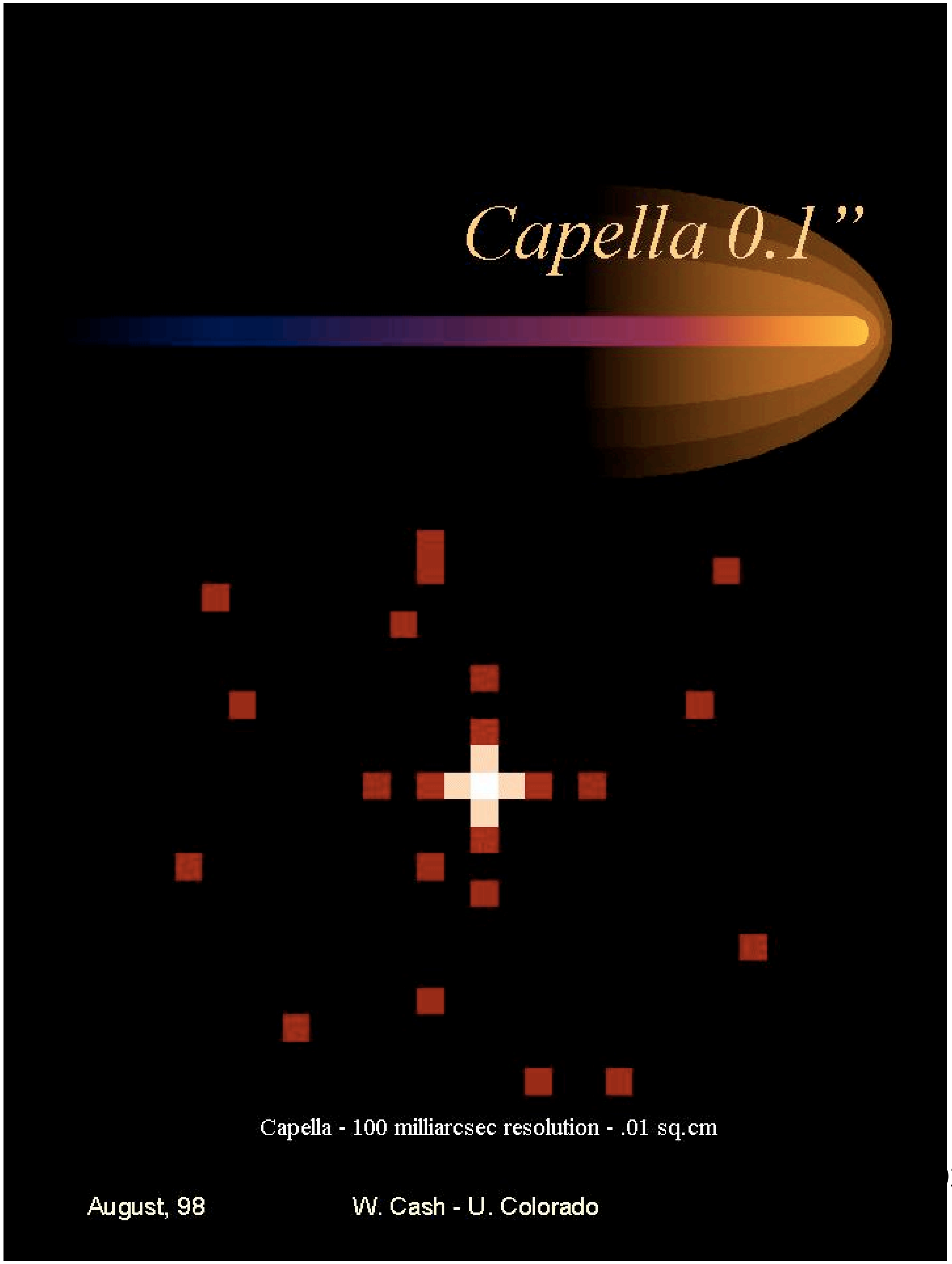
X-ray Interferometry II

The X-ray band is the natural place for interferometry !

- Microarcsecond resolutions are possible with a baseline of ~10 meters.
- X-ray sources have very high surface brightness on microarcsecond scales.

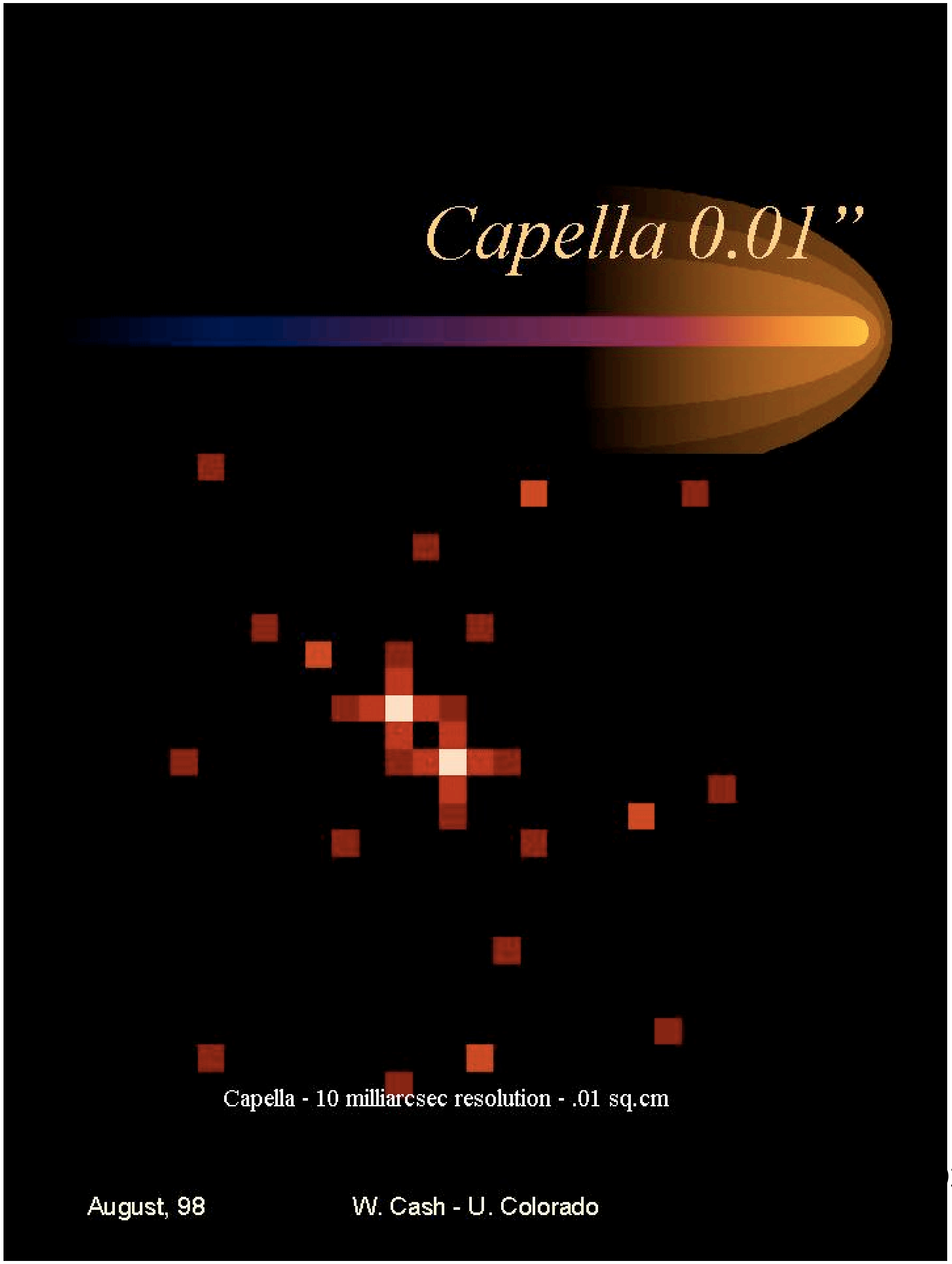
X-ray interferometry allows virtual interstellar travel…

100 milliarcseconds

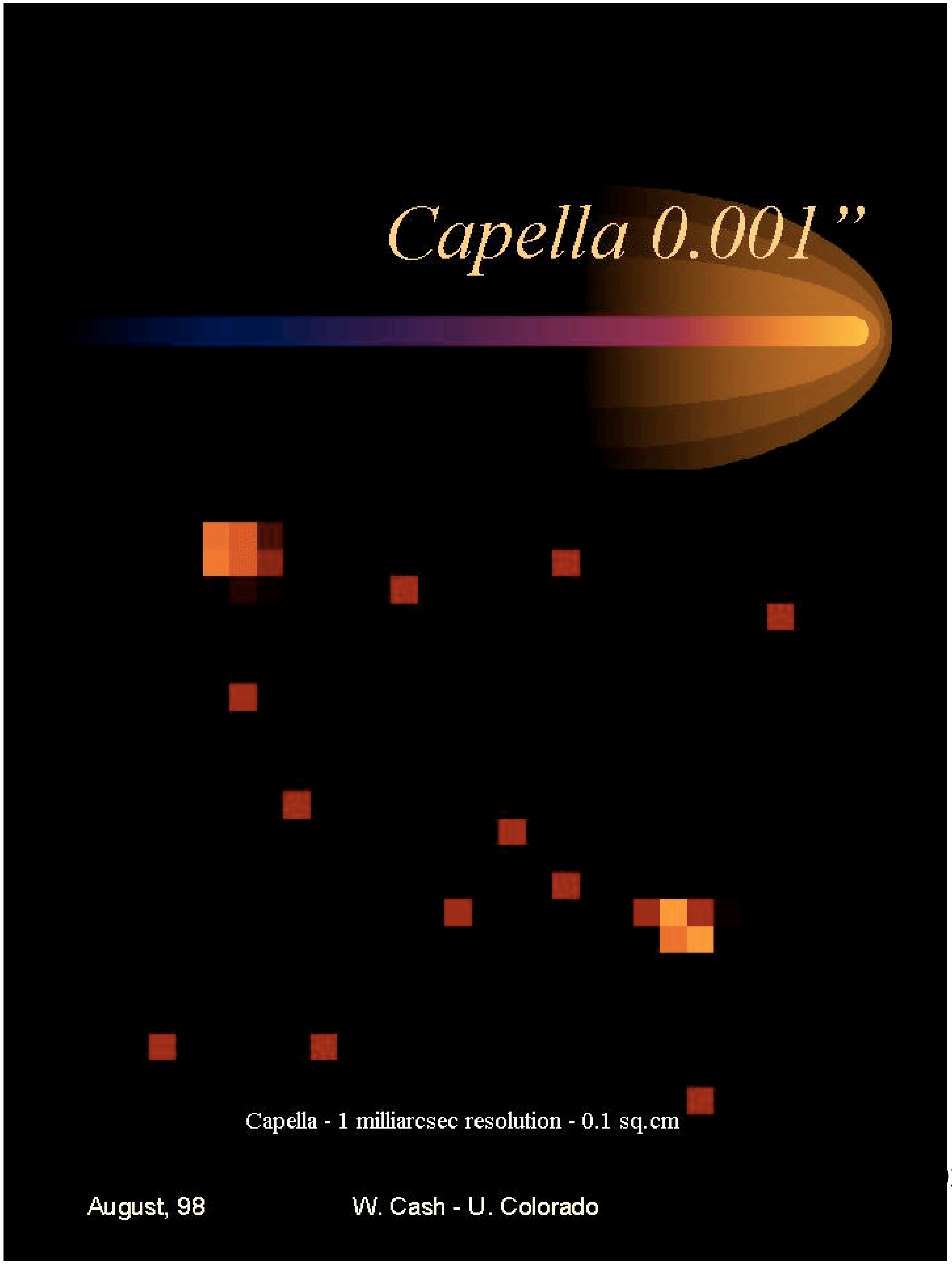


3

10 milliarcseconds

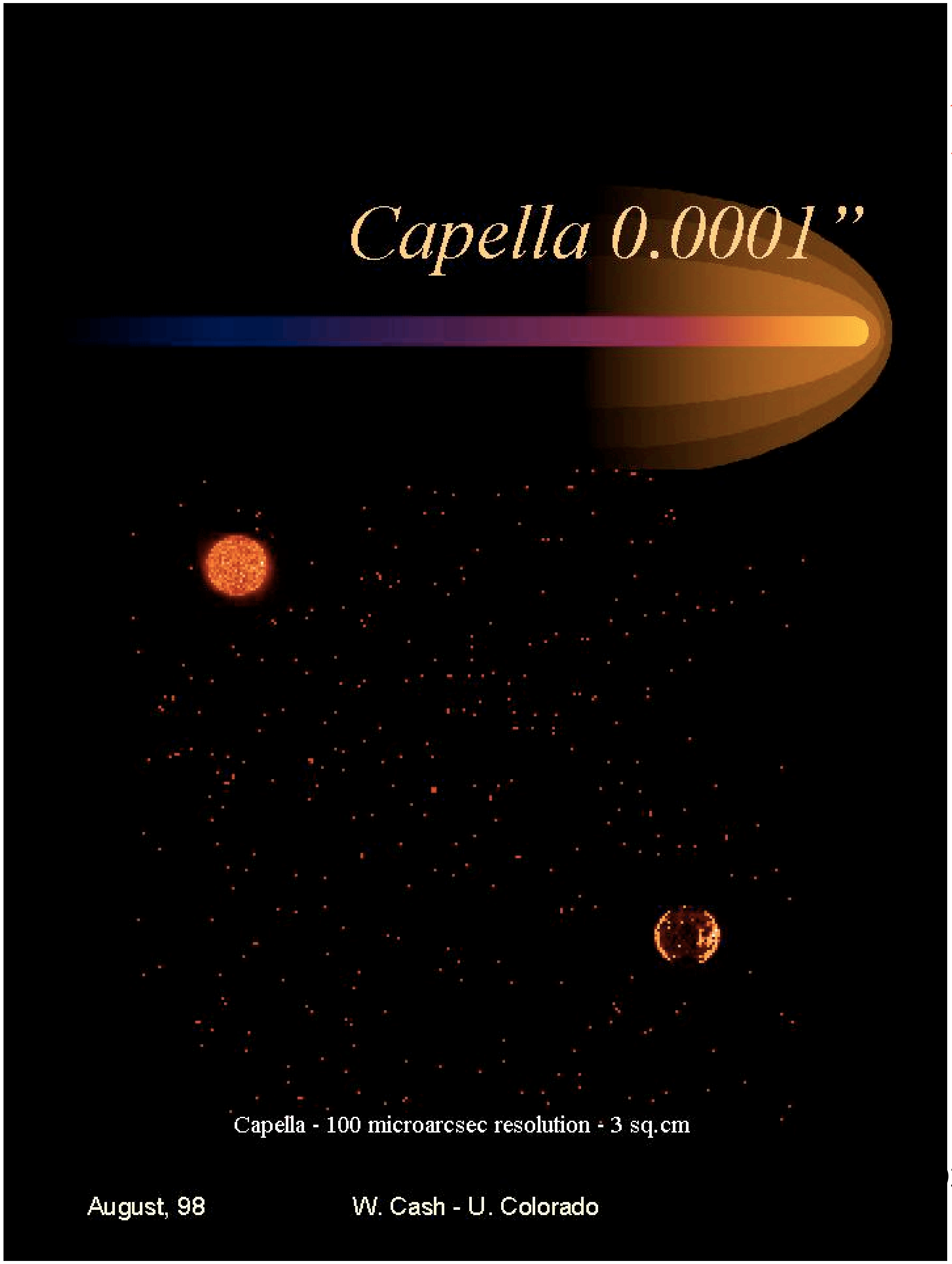


1 milliarcsecond



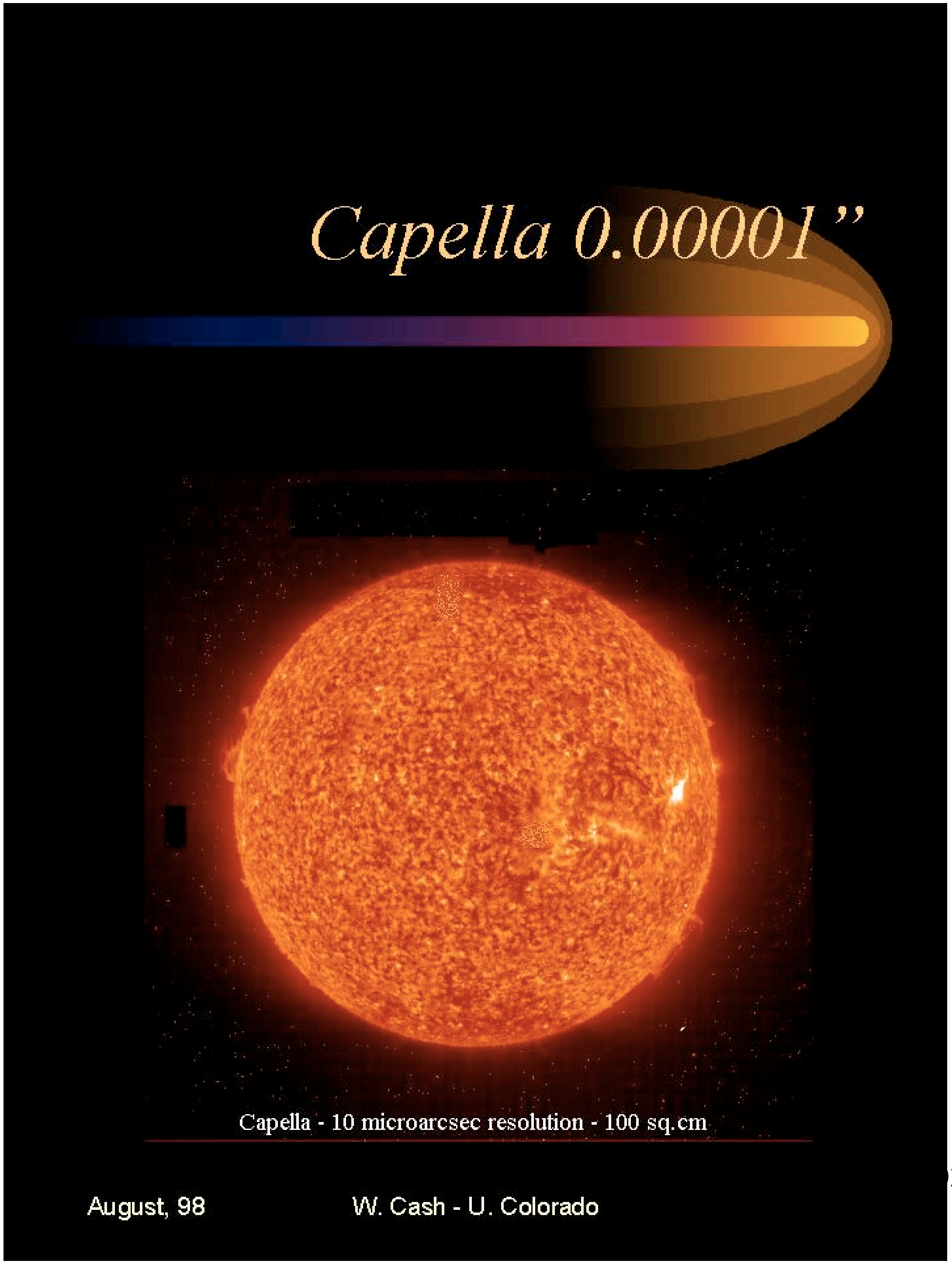
3

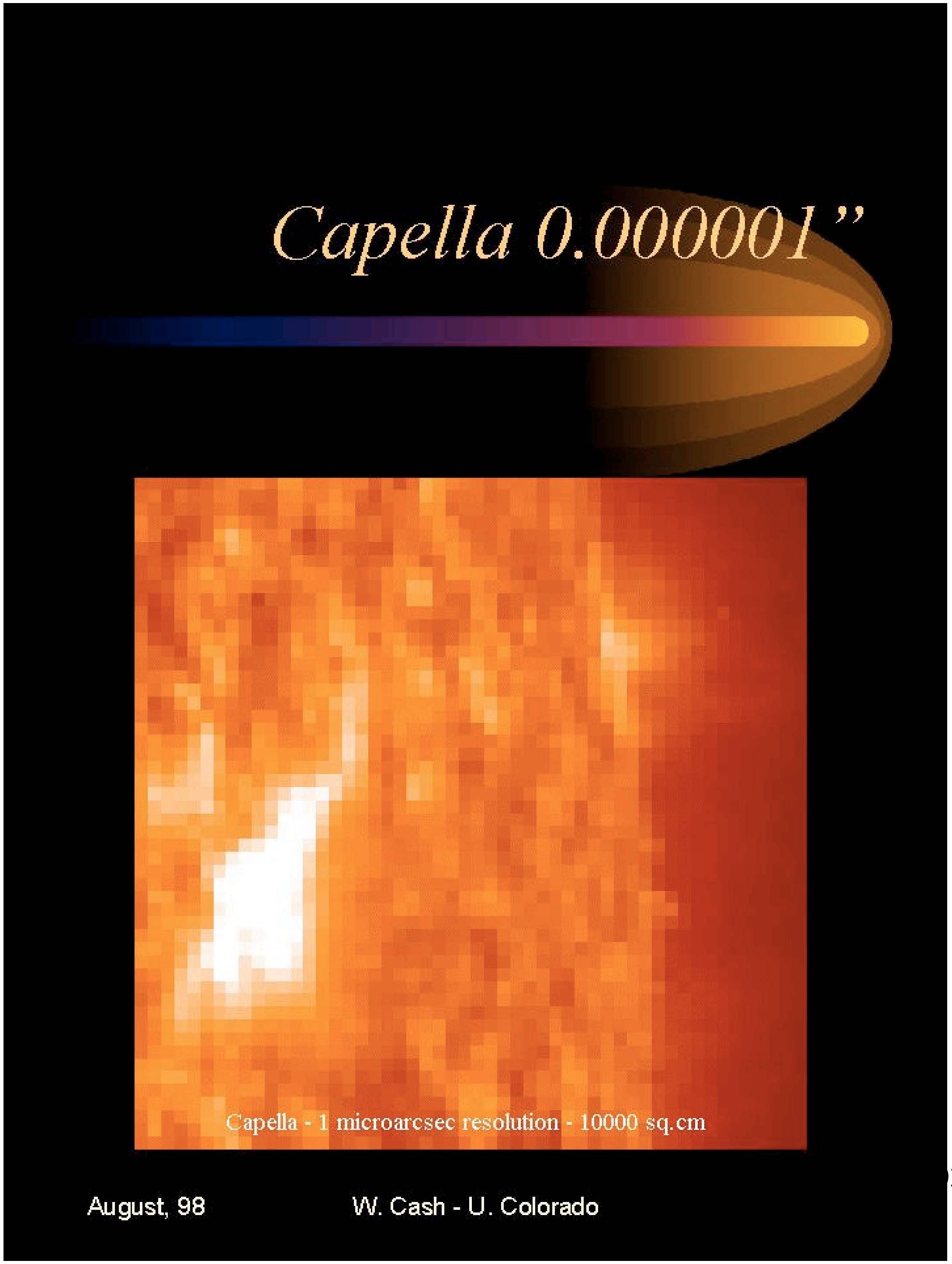
100 microarcseconds



3

10 microarcseconds



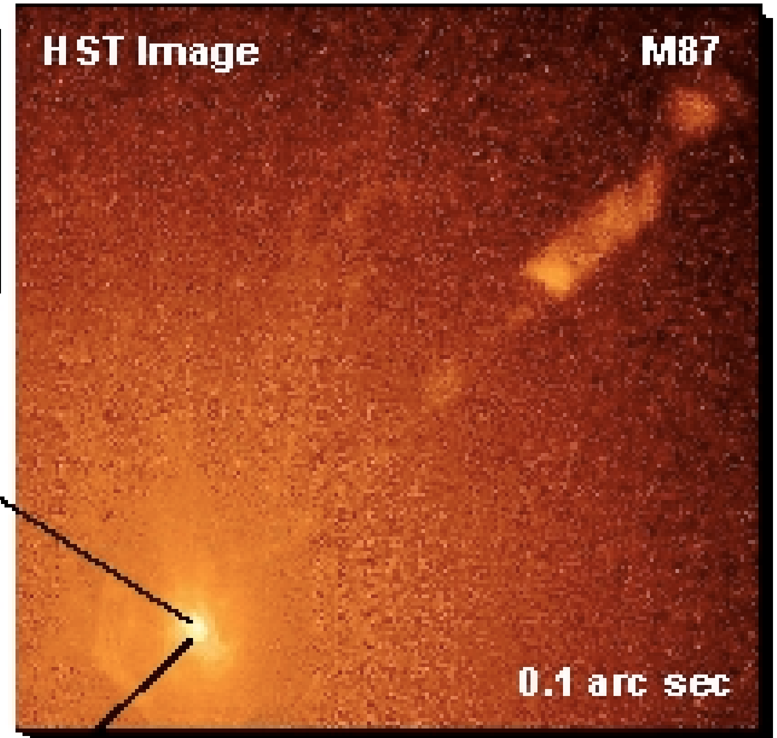


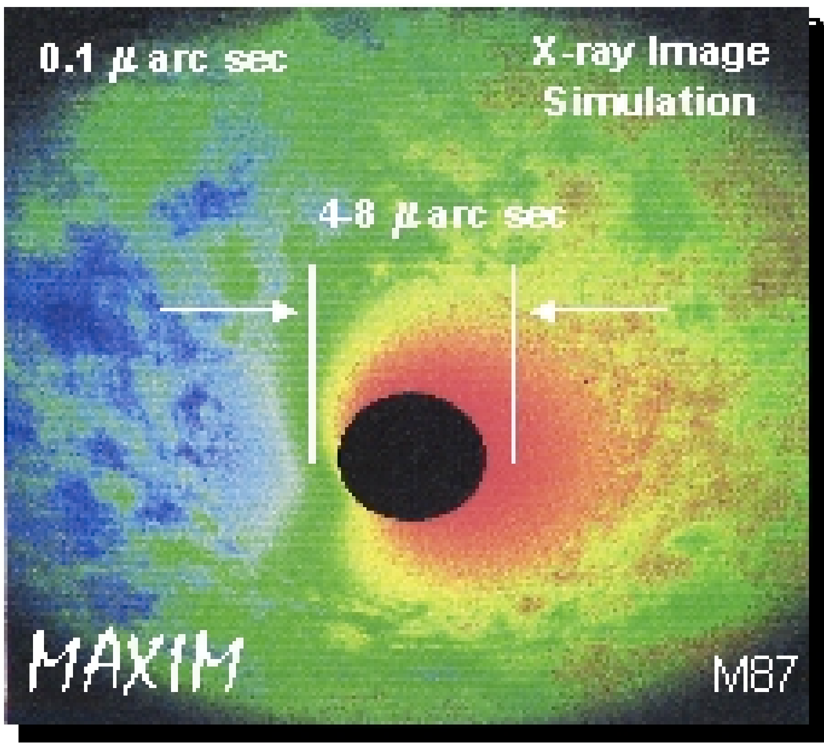
1 microarcsecond

MAXIM Micro Arcsecond X-ray Imaging Mission

Take direct image of a black hole event horizon

- Ultimate journey to visit a black hole
- Fundamental importance to physics
- Will capture the public imagination





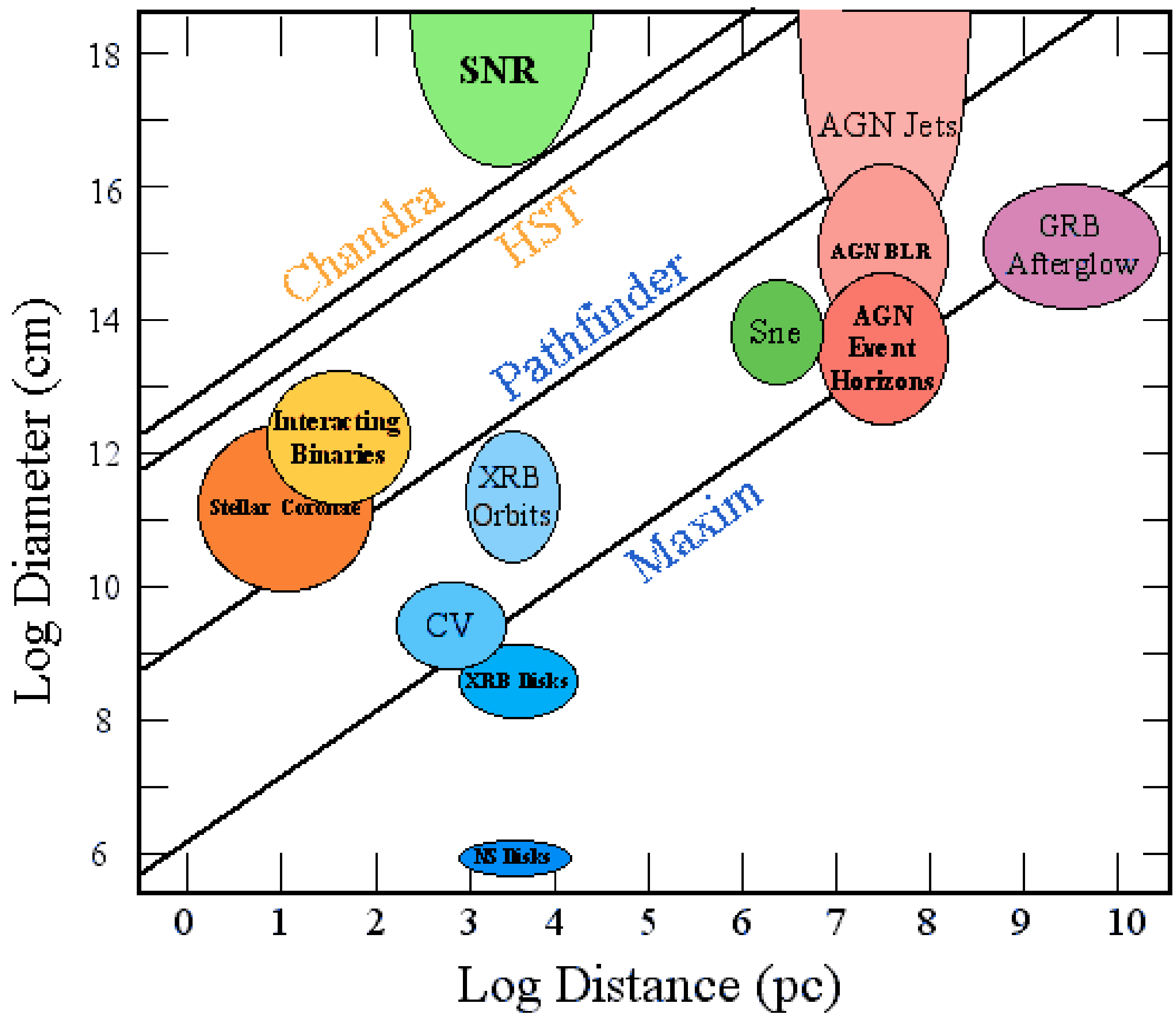
Requires 0.1-1 μ arc second imaging

X-ray interferometry is the best approach

- Baseline of 20 m at 1 Å for 1 μ arc second
- Close to event horizon, energy is emitted in X-rays

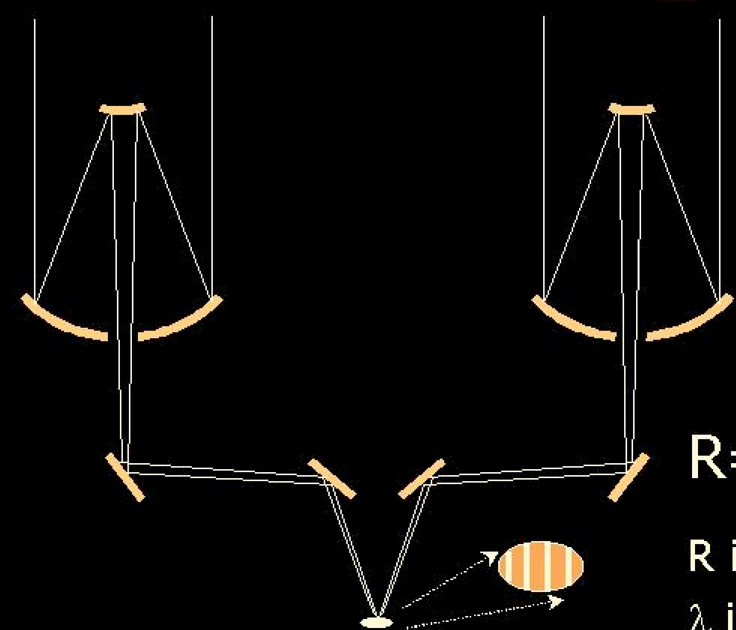
http://maxim.gsfc.nasa.gov

Scientific Goals



Concept:

Michelson Stellar Interferometer



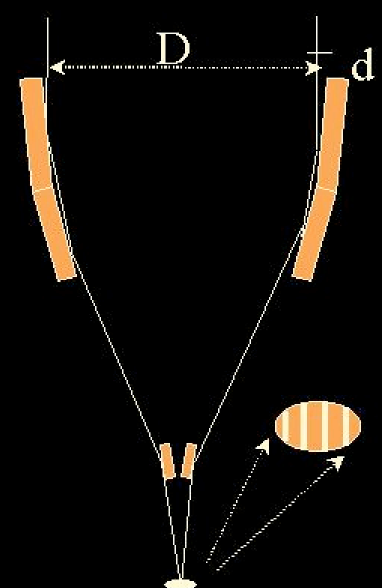
$R = \lambda / 20000D$

R in Arcsec

λ in Angstroms

D in Meters

Grazing Incidence Analog



$$R=\lambda/20000D$$

R in Arcsec

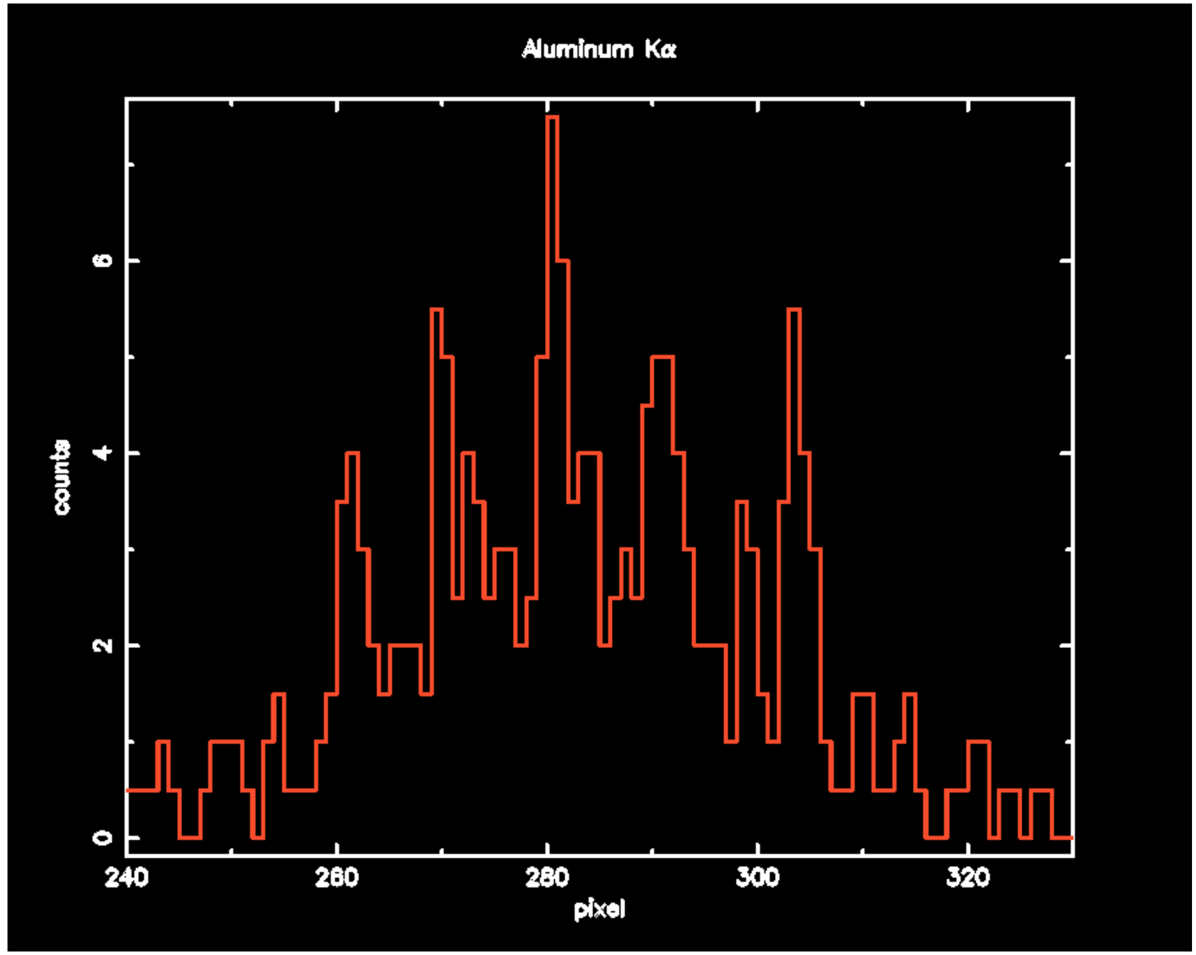
λ in Angstroms

D in Meters

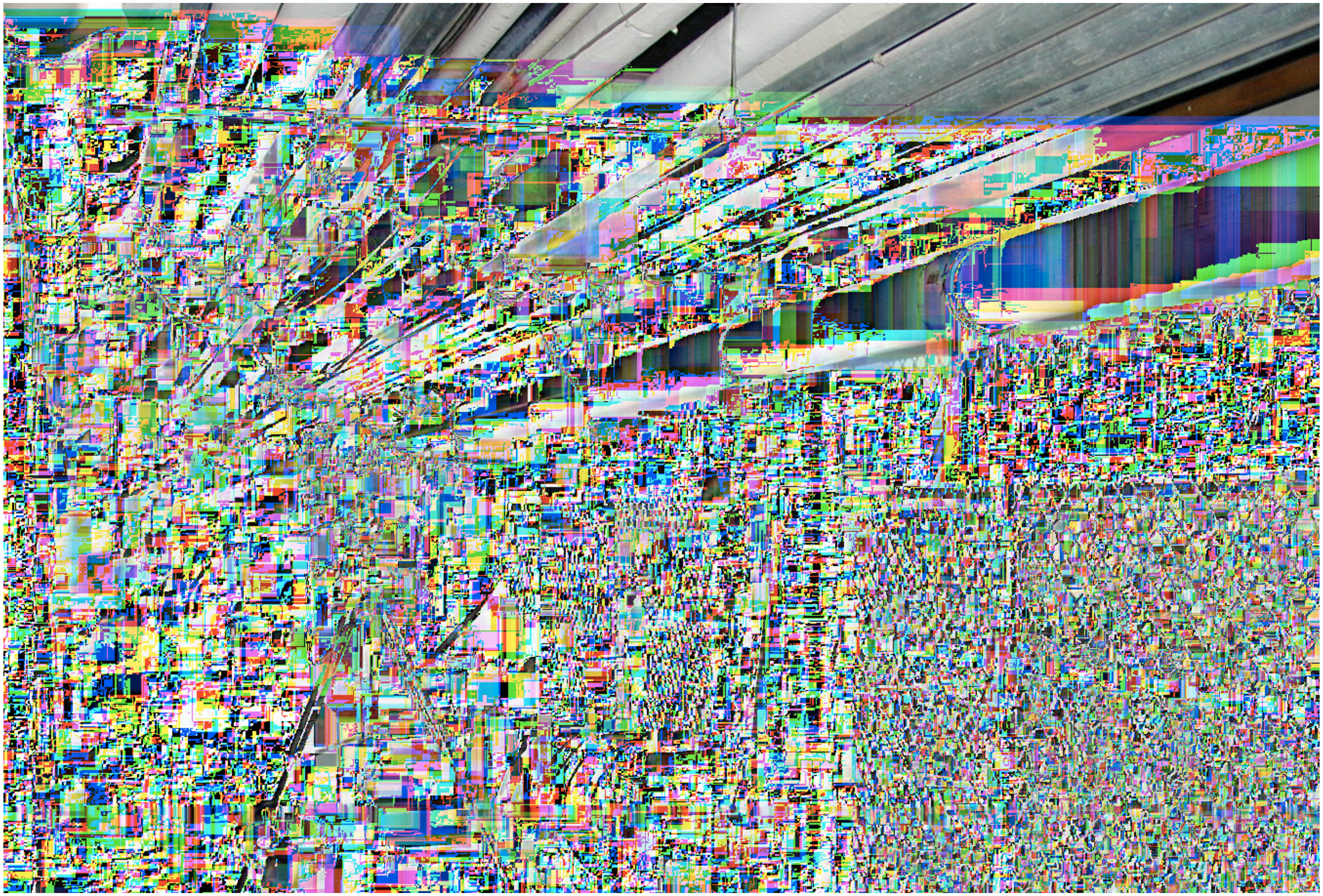
Laboratory test

Fringes at 8.35 Å

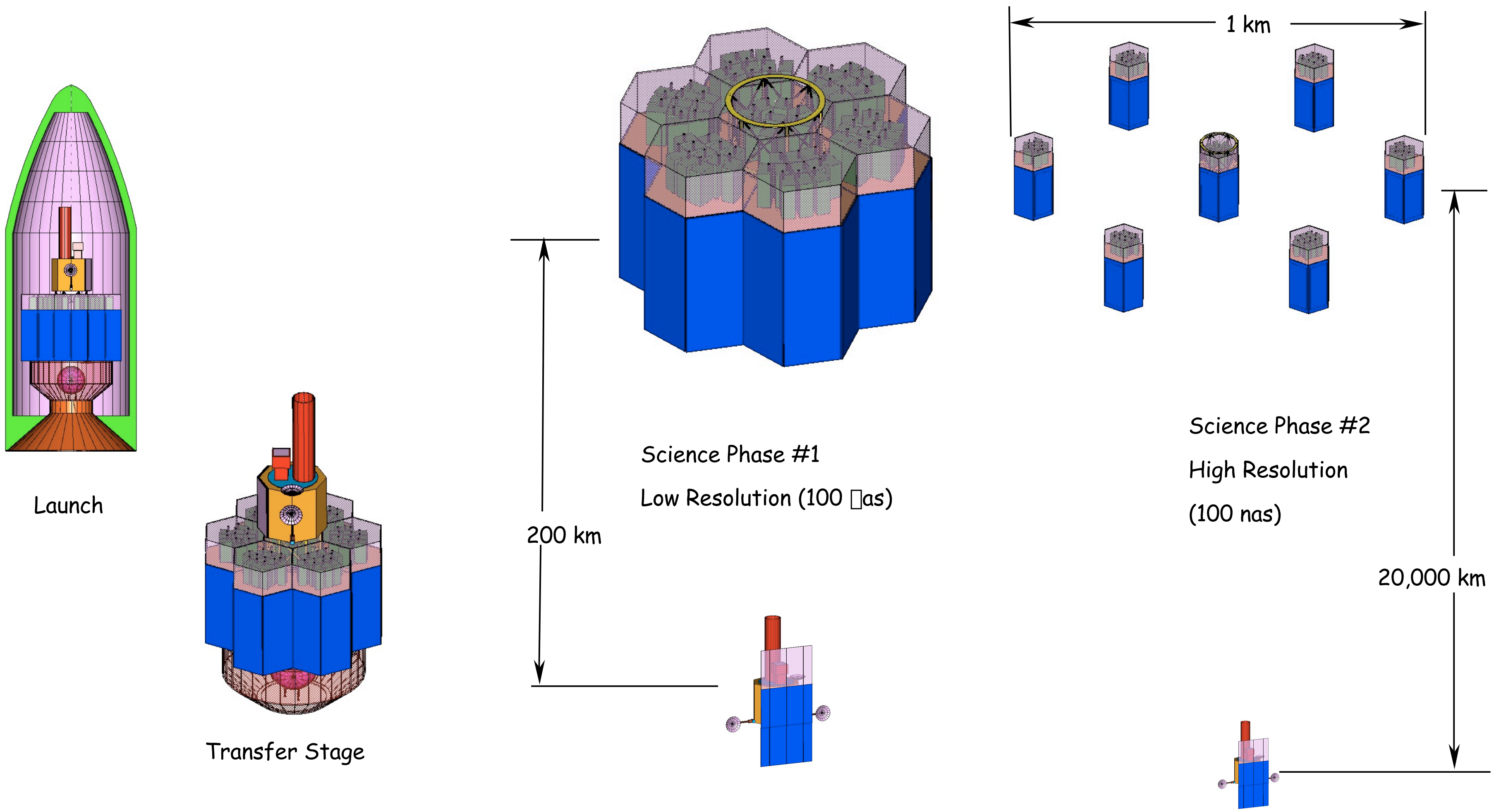
25 November 2002



Test set-up at Goddard



MAXIM Pathfinder



Timeline

2004	Swift (US)
2005	Astro-E2 (Japan-US)
2007	Astrosat (India)
2009?	NeXT (Japan-?)
2013?	Constellation-X (US)
2015??	XEUS (ESA), Maxim Pathfinder (US)
2025???	Generation-X (US), Maxim (US)